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DEVELOPMENT OF CdS-DOPED GLASS OPTICAL FIBERS FOR ALL-OPTICAL SWITCHING

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13. ABSTRACT *(Maximum 200 words)*

We have successfully fabricated samples of CdSSe-doped fibers made from RG630 Schott glass and designed for single-mode operation in the 1300nm and 1550nm communication wavelength region. The linear absorption coefficient of the CdSSe-doped fiber was measured to be 0.14 dB/cm. A comparison between the measured transmittance of a sample of 350um O.D. fiber and a bulk rod of RG630 Schott glass shows the two to have similar characteristics. That is, (i) the absorption edge of the fiber and the RG630 are found to be the same and near 630nm, and (ii) the region of maximum transmittance occurs beyond 680nm for both fiber and RG630. The transmittance remains relatively constant for wavelengths greater than 680nm. These results point to the fact that the fabrication of the fiber yielded good samples. Also we have developed an experimental procedure to gain switch the probe signal. This capability will be employed for time synchronization of pump and probe in the switch implementation. We have measured the nonlinear refractive index of the RG630 glass at 1313nm. The nonresonant nonlinear refractive index for a CdSSe-doped fiber has been determined experimentally, at a wavelength of 1313nm and found to be 1.8×10^{-17} m^2/W. In comparison, silica fiber has an n_2 value of 4.2×10^{-20} m^2/W.

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Abstract:

We have successfully fabricated samples of CdSSe-doped fibers made from RG630 Schott glass and designed for single-mode operation in the 1300 nm and 1550 nm communication wavelength region. The linear absorption coefficient of the CdSSe-doped fiber was measured to be 0.14 dB/cm. A comparison between the measured transmittance of a sample of 350 μm O.D. fiber and a bulk rod of RG630 Schott glass shows the two to have similar characteristics. That is, (i) the absorption edge of the fiber and the RG630 are found to be the same and near 630 nm, and (ii) the region of maximum transmittance occurs beyond 680 nm for both fiber and RG630. The transmittance remains relatively constant for wavelengths greater than 680nm. These results point to the fact that the fabrication of the fiber yielded good samples. Also we have developed an experimental procedure to gain switch the probe signal. This capability will be employed for time synchronization of pump and probe in the switch implementation.

We have measured the nonlinear refractive index of the RG630 glass at 1313 nm. The nonresonant nonlinear refractive index for a CdSSe-doped fiber has been determined experimentally, at a wavelength of 1313 nm and found to be 1.8×10^{-17} m^2/W. In comparison, silica fiber has an n_2 value of 4.2×10^{-20} m^2/W [1]. This value of n_2 is therefore 400 times higher than silica fiber. The results obtained to date are promising and the overall project is proceeding in accordance with stated objectives.

I. Introduction:

The goal of this project is to design and implement a compact fiber-based all optical switch actuated at laser diode power levels. The operation of the devices is based on intensity induced wavelength shift of a probe signal in a Kerr medium. A semiconductor (CdSSe -) doped specialty fiber serves as the Kerr medium. The switch is an integrated structure of the specialty fiber with fiber grating. The structure is designed such that the transmission wavelength of the gratings coincides with the probe or signal wavelength. Thus in the absence of a pump pulse the probe will be transmitted. This corresponds to the "ON-state" of the switch. The intensity of the pump is chosen in order to cause a shift in the wavelength of the probe, equal to or greater than the band stop of the grating, and thereby cause the probe to be reflected. This corresponds to the "OFF-State" of the switch. This report is a summary of activities completed to date.

II. Activities Completed.

A. Fabrication Of CdSSe-Doped Fiber

A number of CdSSe-doped fibers have successfully been fabricated and their linear properties characterized. The fiber was fabricated using Schott glass RG630, with a $CdS_{0.5}Se_{0.5}$ composition as the core material, and RG6 as the cladding material. The diameters of the fiber core range between 3-8 μm, and the outer diameter of the fiber range between 150 - 350 μm. The table below summarizes the different types of fibers fabricated.

TABLE 1: CdSSe-doped fibers fabricated with RG-630 core glass and RG-6 cladding glass. The refractive index of the cladding (RG6) was measured to be 1.522.

Sample	Estimated Core Diameter (μm)	Outer Diameter (μm)
A	3.2	150
B	4.3	200
C	5.3	250
D	6.4	300
E	7.4	350

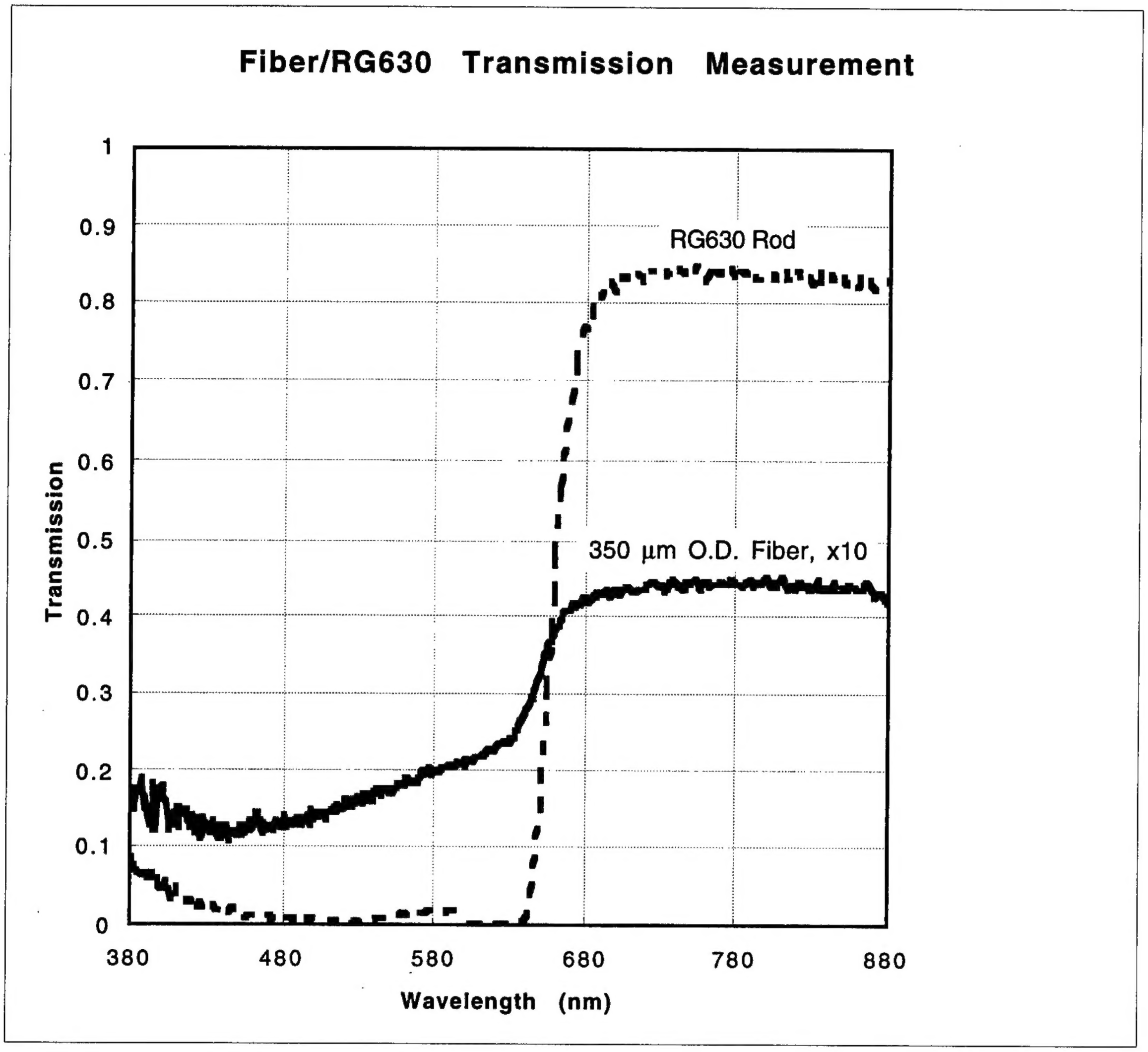

Figure 1 White light transmission measurement of RG630 1 mm diameter glass rod (dashed curve) and CdSSe-doped optical fiber (solid curve).

B. Measurement Of the Transmittance Spectra Of CdSSe-Doped Fiber.

The transmittance of the fiber over a wavelength range between 380 and 880 nm was measure using a tungsten filament white light source. The white light source was focused onto one end of an approximately 16 cm length of Sample E fiber. The output end of the sample fiber was focused on to the input aperture of an ANDO AQ1425 Optical Spectrum Analyzer. The transmission measurement of the Sample E fiber is shown in

Figure 1. For comparison, the transmission measurement results of a 2.5 cm long rod of the RG630 core material is also included. The quantitative levels of the two measurements are greatly different. This difference is due to the diffraction limited focusing of the white light filament reducing the available power one is able to launch into the core of the fiber. Qualitatively, however, the position of a measured absorption edge is the same for both materials and located near the expected value of 630 nm for this glass type. This result indicates that the CdSSe of the RG630 glass material has survived the fiber fabrication process and should result in similar properties as that found in the bulk material.

C. Measurement Of The Absorption/Scattering Coefficient Of Fiber.

A cut-back method was used to measure the linear absorption coefficient of the fiber. The set-up for this experiment is as shown in Figure 2. The source is a 1532 nm DFB pig-tailed semiconductor laser diode. The test fiber was mounted on two flexure-stages. The pig-tailed laser was butt- coupled to one end of the fiber. An optical imaging system, located at the opposite end of the test fiber and comprised of an IR photocathode camera and a monitor, was used to observe and ensure that the source signal was well coupled into the core of the fiber before performing the cut-back measurement. Imaging results indicated that a large amount of scattering occurs in the sample fibers and is probably the largest contribution to the measured absorption coefficients. A standard single-mode fiber SMF-28 was used to collect the light from the sample fiber and deliver the power propagating in the core of the fiber to a photodiode detector. A Newport 835 power meter with an 818-IR detector was used to measure the output power.

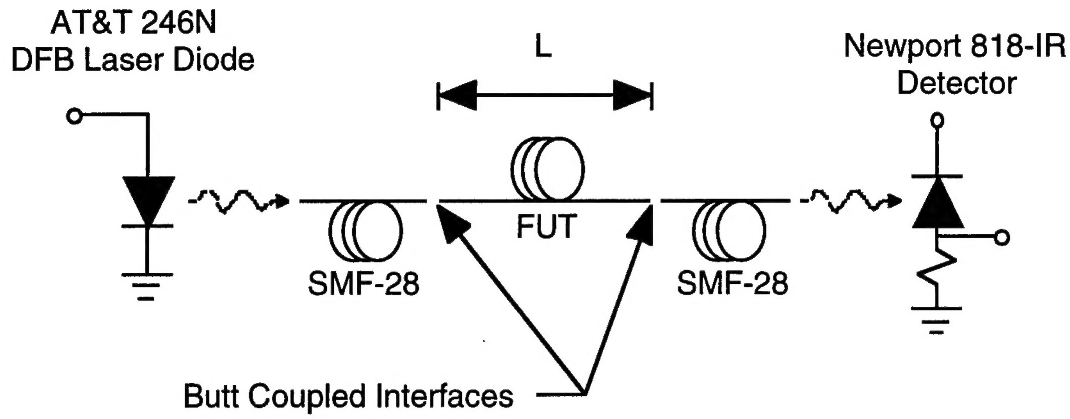

Figure 2 Schematic diagram of experimental setup used for cut-back measurement of optical fiber absorption coefficient.

An initial length L(about 50 cm) of the test fiber was used. The output power was measured for different input power levels to insure linear absorption. A known length of fiber was then cut-off from the detector end of the test fiber, and the output power again measured for the same set of input power levels. This procedure was repeated for additional cut-backs and an average of the results was made after calculating the absorption coefficient according to,

$$\alpha = \frac{1}{L} 10 \log \frac{P_{out1}}{P_{out2}} \, dB/cm$$

where, P_{out1} is the measured output power prior to cutting and P_{out2} is the measured output power after the cut back.

Table 2 gives a set of measurements for the cut-back experiment and the calculated absorption coefficient. An average value of the absorption coefficient gave a value of 0.14 dB/cm. Excess losses due to butt-coupling totaled -5.4 dB. Assuming -0.6 dB for Fresnel losses at the glass/air interfaces, excess coupling losses are -4.8 dB.

TABLE 2. Cut-back results.

			DL = 25.3 cm	DL = 30.6 cm	Absorption Coefficient	Absorption Coefficient
Laser Bias (mA)	Pout DFB (mW)	Pout L=101.6 cm (μW)	Pout L=76.3 cm (μW)	Pout L=45.7 cm (μW)	(dB/cm) # 1	(dB/cm) # 2
20	0.8283	8.9	20.3	54.3	-0.1415439	-0.1396418
22.5	1.0538	11.5	26	70	-0.1400298	-0.1405636
25	1.2805	14	32	82	-0.1419059	-0.1335503
27.5	1.5205	16.4	37	102	-0.1396671	-0.1439211
30	1.76	19.5	43.6	115	-0.1381233	-0.1376508
				Ave. -->	-0.140254	-0.1390655

D. Measurement of n_2 For CdSSe-Doped Glass at 1313 nm

Two experimental studies have been conducted, at present, to study the nonlinear optical properties of the CdSSe-doped fiber. One study is a measurement of the nonlinear refractive index, n_2, of the fiber at 1313 nm. At this wavelength, the optical nonlinearity of the CdSSe-doped glass fiber is due to a non-resonant mechanism. As such the nonlinearity should have a fast response time. We therefore conducted a comprehensive literature search to obtain n_2 data for CdSSe in a glass matrix composition or bulk-CdSSe. The pertinent results are summarized in Table 3. As seen from the table, the n_2 values given do not include data for 1313 nm.

TABLE 3. Literature references of measured values for the nonlinear refractive index n_2 for various glass compositions and wavelengths.

Material	Type	Energy gap (eV)	Wavelength (μm)	$n_2 \times 10^{-13}$ cm^2/W	Reference
$CdS_{.9}Se_{.1}$	glass/comp	2.35	1.06	8.4	Acioli, *et al.*, Appl. Phys. Lett. **54**(20), 1956 (1989).
$CdS_{.9}Se_{.1}$	glass/comp	2.35	0.530	420	Olbright *et al.*, Appl. Phys. Lett., **48**(18), 1184 (1986).
$CdS_{.9}Se_{.1}$	glass/comp	2.35	0.532	2730	Jain & Lind., J.

	.				Opt. Soc Am. B, **73**, 647 (1983).
$CdS_{.8}Se_{.2}$	glass/comp.	2.28	0.589	21100	Remillard, *et al.* Opt. Lett., 13 (1), **30** (1988).
$CdS_{0.7}Se_{0.3}$	glass/comp	2.21	0.570	2110	Roussignol, P., J. Opt. Soc. Am. B, **4**(1), 5 (1987).
CdS (size 3nm)	glass/comp.	2.42	1.9	69	Cheng, *et al.*, J. Appl. Phys, **66**(7), 3417 (1989).
CdS (size 1.5nm)	glass/comp.	2.42	1.9	5.3	Cheng, *et al.*, J. Appl. Phys, **66**(7), 3417 (1989).
fused silica	bulk	7.8	1.06	0.021	Sheik-Bahae, *et al.*, J. Quantum Elec., **27**(6), 1296 (1991).
fused silica	bulk	7.8	.249	0.034	Sheik-Bahae, *et al.*, J. Quantum Elec., **27**(6), 1296 (1991).

The approach for the measurement of the nonlinear refractive index follows a Z-Scan method proposed by Sheik-Bahae, *et al.* [2] The experimental set-up is as shown in Figure 3. The laser source is a 1313 nm mode-locked Nd:YLF laser emitting pulses of 95 ps duration and having peak power of 100W at a repetition rate of 100 MHz. A beam splitter (BS) splits part of the pulse to detector, D1. The remaining portion of the beam is focused on to the sample (S). The sample is 3-mm thick RG630 Schott glass, the same material used as the core material for the specialty fiber. An adjustable aperture is place on one side of the sample as shown in Figure 3. A second detector, D2, is placed behind the detector.

Z-Scan experimental set-up for measuring n_2

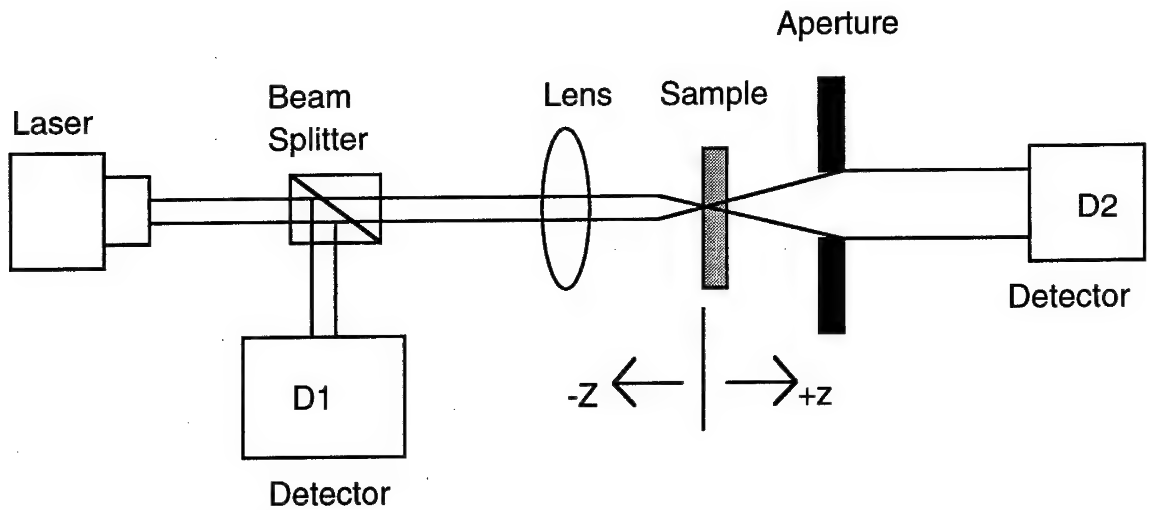

Figure 3. Z-scan experimental setup.

The set-up measures the transmittance of the sample as a function of position between the focusing lens and the aperture. The change in the transmittance has been shown to depend on the nonlinearity of the material according to the formula:

$$n_2(esu) = \frac{\Delta T_{p-v}}{I_o(t)}\left[\frac{1}{0.046(1-S)^{0.25}}\right]\frac{2\pi}{\lambda}\frac{\alpha}{1-e^{-\alpha L}}\frac{2n_o}{40\pi}$$

In this equation, $\Delta T_{p\text{-}v}$ is the peak-to-valley change in transmittance, $I_0(t)$ is the peak intensity of the laser source signal, S is the aperture linear transmittance, L is the sample thickness and n_0 is the linear refractive index of the sample. The result for a position-dependent transmittance of a 3-mm thick sample of RG630 glass is shown in Figure 4. The peak power of the laser pulse was 157W. The experiment was repeated for power levels of 128W, 170W, and 199W. From the measured transmittance and the equation

above, the nonlinear refractive index for the CdSSe/glass composite was determined to be 1.8×10^{-17} m^2/W.

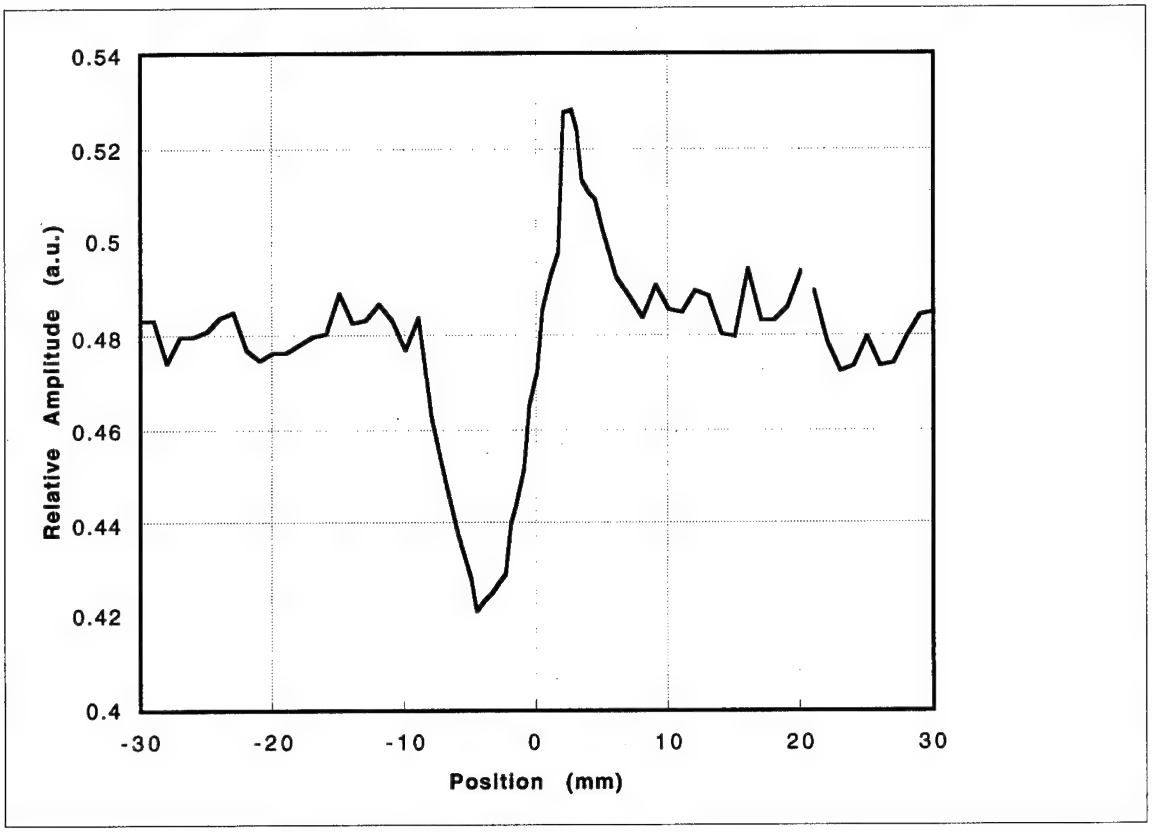

Figure 4. Z-scan measurement of 3 mm thick RG630 glass.

E. Pump-Probe Experiment.

A pump-probe experiment will be used to measure the intensity induced wavelength shift in the CdSSe-doped fiber samples. The pump signal is the 1.313 μm mode-locked Nd:YLF laser, while the probe signal will be a gain switched 1.532 μm DFB semiconductor laser diode synchronized to a higher harmonic of the repetition rate of the pump laser. The optical spectrum of the gain switched probe laser is shown in Figure 5. The pump is expected to induce a wavelength shift in this optical spectrum. The equation for the wavelength shift is given as [3],

$$\delta\lambda = \frac{2\lambda^2 n_2 P_p L_{eff}}{c\lambda_0 A_{eff} T_0}$$

where, λ is the probe wavelength, λ_0 is the pump wavelength, P_p is the peak power of the pulse, L_{eff} is the effective length of the fiber (since pulse walk off is assumed to be negligible), A_{eff} is the effective core area and T_0 is the 1/e width of the pulse. For the above values, this equation reduces to,

$$\delta\lambda = 4.24x10^{-5} \frac{n_2 P_p}{T_{FWHM}}$$

where T_{FWHM} is the full-width at half maximum of the pump pulse, and where we have used a core radius of 4 μm and a fiber sample length of 100 cm. Assuming a peak pump pulse power of 10 W, a T_{FWHM} of 95 ps and using an n_2 of 8.4x10-17 m^2/W, a wavelength shift of 0.374 nm is expected. This value is clearly resolvable by the optical spectrum analyzer as illustrated in Figure 5.

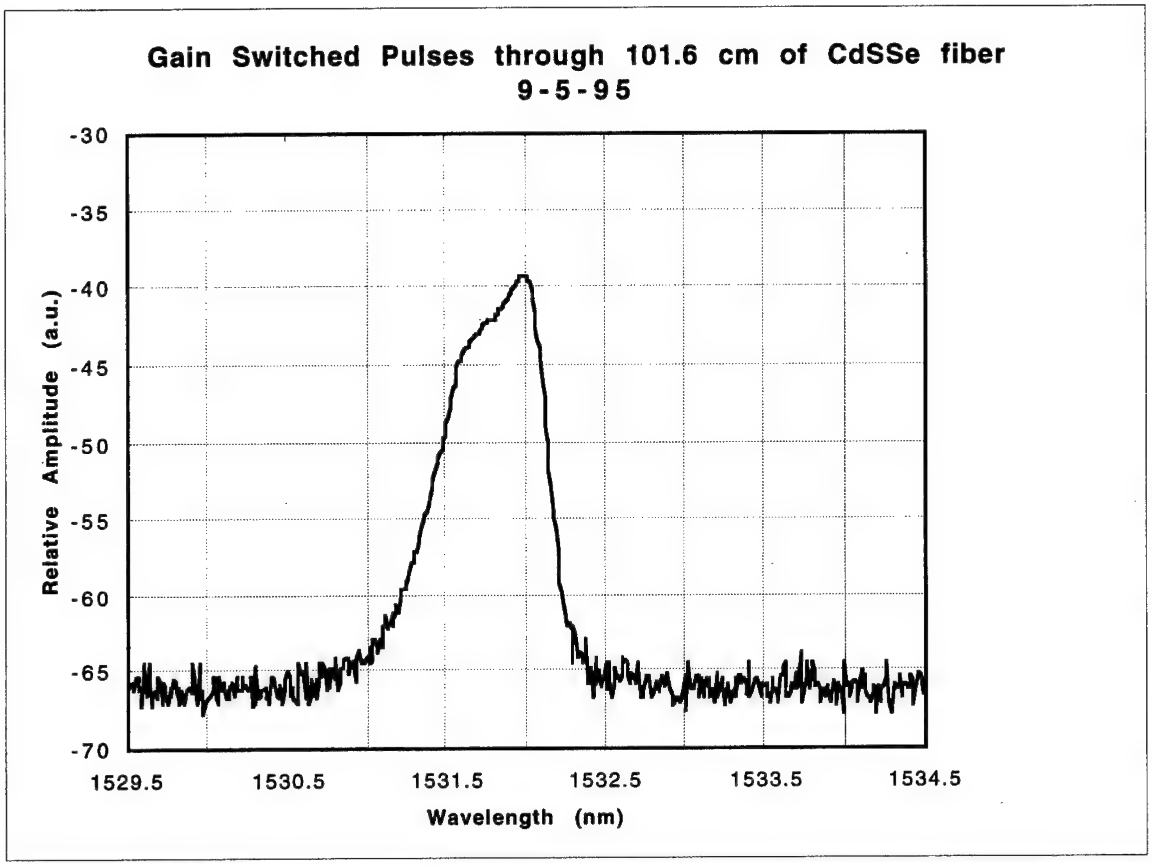

Figure 5. Optical spectrum of gained switched DFB laser pulse.

III. Summary:

We have successfully fabricated samples of CdSSe-doped fibers designed for single-mode operation in the 1300 nm and 1550 nm communication wavelength region. The linear absorption coefficient of the CdSSe-doped fiber was measured to be 0.14 dB/cm. A comparison between the measured transmittance of a sample of 350 μm O.D. fiber and a bulk rod of RG630 Schott glass depicted in fig. 1 shows the two to have similar characteristics. That is, (i) the absorption edge of the fiber and the RG630 are found to be qualitatively similar and near 630 nm, and (ii) the region of maximum transmittance occurs beyond 680nm for both fiber and RG630. The transmittance remains relatively constant for wavelengths greater than 680nm. These results point to the fact that the fabrication of

the fiber yielded good samples. Also we have developed an experimental procedure to gain switched the probe signal. This capability will be employed for time synchronization of pump and probe in the switch implementation.

The measurement of the nonlinear refractive index of the fiber at 1313 nm along with the measurements performed to date will provide the information that determines the usefulness of these fiber samples in all optical switching. The results obtained to date are promising and the overall project is proceeding in accordance with stated objectives.

IV. References:

1. N. Sugimoto, Appl. Phys. Lett. **66**(8), 923 (1995).

2. M. Sheik-Bahae, *et al.*, IEEE J. Quantum Electron, **27**(6), 1296 (1991).

3. P.L. Baldeck, et al, Appl. Phys. Lett., **52** (23) 1939 (1988).

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